Design and Analysis of Antennas operating at different frequency bands using CST

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Design and Analysis of Antennas operating at different frequency bands using CST

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by

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C E R T I F I C A T E

This is to certify that the thesis entitled ***"Design and Analysis of Antennas operating at different frequency bands using CST"*** *by* ***Mr. PUDU ATCHUTARAO****, submitted to the National Institute of Technology, Rourkela (Deemed University) for the award of Master of Technology in Electrical Engineering, is a record of bonafide research work carried out by him in the Department of Electrical Engineering , under my supervision. I believe that this thesis fulfills the requirements for the award of degree of Master of Technology.The results embodied in the thesis have not been submitted for the award of any other degree elsewhere.*

Prof.K. R. Subhashini

Place:Rourkela

Date:

To My family, friends and Inspiring GUIDE

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Contents

Abstract

Spherical microstrip antenna arrays have a great practical interest because they can direct a beam in an arbitrary direction throughout the space. The characteristics i.e. without limiting the scan angles, differently from the planar antenna behaviour makes them very suitable for use in communication satellites and telemetry. As far as circular array antennas are concerned, the quality of the radiation pattern will not be impaired when scanned in the full azimuthal axis. Spherical array antennas have the unique property of scanning their beam with no deterioration in full spherical coverage (i.e. azimuth and elevation axes). In this work a spherical microstrip antenna array of 16 elements has been designed. The basic element of this array is a rectangular patch antenna with operating frequency at 5.35 GHz. All the 16 elements were mounted on spherical surface in order to design the spherical microstrip antenna array with an operating frequency of 5.35 GHz. The operating frequency has been chosen such that it can be operated in C-Band for satellite communication.

Power divider circuits are very important components in many microwave subsystems and circuits. These are very commonly used in mille meter wave circuits (antenna array feed networks, balanced mixers, amplifiers and phase shifters). A power divider must be matched at all ports so that it will be lossless, it must provide isolation between output ports. The Wilkinson power divider is a power divider which has excellent isolation between two output ports. A basic Wilkinson power divider has two in-phase output ports. The

Wilkinson power divider can be matched at all 3 ports. It is loss less if the output ports are matched, reciprocal and largely isolated. In this thesis work a 2-way, 4-way and 8-way equal and 4-way unequal power dividers are designed using the conventional Wilkinson topology.
Two more designs were included in this work. One is ultra-wide band antenna and other is Zigzag antenna. First one is designed for Body Area Network (BAN) applications to operate within the range 3.1GHz 10.6GHz i.e. Ultra Wide Band range. Remove this line. Second one is Zigzag antenna, designed for a Radio telescope antenna. The high directivity of the Zigzag antenna can be utilized advantageously in the VHF and UHF ranges. All the designs were done using electromagnetic simulator, Computer Simulation Technology (CST) Microwave Studio.

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List of Abbreviations

Abbreviation	Description
IEEE	Institute of Electrical and Electronics Engineers
CST	Computer Simulation Technolody
EM	Electromagnetic
FDTD	Finite-difference Time-Domain
Wi-MAX	World Interoperability for Microwave Access
WLAN	Wireless Local Area Network
FCC	Federal Communications Commission
UWB	Ultra Wide Band
BAN	Body Area Network
GPR	Ground Penetrating Radar
MSA	Microstrip Antenna
ASP	Aperture Stacked Patch
MMIC	Monolithic Microwave Integrated Circuit
PEC	Perfect Electric Conductor
DGS	Defective Ground Structure
HPBW	Half Power Beamwidth
SLL	Side Lobe Level
RF	Radio Frequency
HF	High Frequency
VHF	Very High Frequency
UHF	Ultra High Frequency
dB	Decibel

Chapter 1

INTRODUCTION

1.1 Introduction

In the present day of antenna technology, microstrip antennas are mostly used in various domains, like modern communications, radar and medical, aerospace etc because of its low profile, less cost, easy process of fabrication and the feasibility of mounting in different geometrical structure needed in so many applications. Microstrip patch antennas consist of a metallic patch of metal that is on top of a grounded dielectric substrate of thickness (h), with relative permittivity. The metallic patch may be of various shapes, with rectangular and circular being the most common. Spherical microstrip antenna arrays have been a subject of great practical interest, with a full range of possibilities including tracking, telemetry and command services for low earth and medium-earth orbit satellites [1], since they can direct a beam in an arbitrary direction throughout space, i.e., without limiting the scan angles, differently from the planar or cylindrical antennas behaviour.

Microstrip feed networks are used to provide current excitations to radiating elements of the spherical microstrip antenna arrays. A Wilkinson power divider such a network, has been designed in this work. Wilkinson power divider makes uses of quarter wave transformers made with microstrip or stripline form so that it is easy to fabricate. It is cheap and high performing power divider used to split power in any ratio. Lossless divider when the output ports are matched i.e. only reflected power gets dissipated [2]. Both equal and unequal division of powers is possible with Wilkinson power dividers.

The microstrip antenna gives narrow band and it is not useful where we need high speed and high bandwidth. UWB antenna is such antenna which has an operating frequency range from 3.1 GHz to 10.6 GHz given by Federal Communication Commission (FCC) in 2002. The frequency band of operation is based on the 10dB bandwidth of the UWB emission. Wireless communications permits UWB technology to overlay already available services such as the Wi-MAX, the IEEE 802.11 WLANs and Body Area Network (BAN) that coexist in the 3.1 to 10.6GHz.

When an antenna designer gone through designing antenna operating in the range Ultra-high frequency, Very high frequency and high frequency, directivity is the main concern. Zigzag antenna is a such type of antenna having high directivity and unidirectional radiation pattern. hence this antenna is very useful where unidirectional and high gain is preferred. This antenna is strongly related to helical antenna but its planar nature is more advantageous where fabrication is concerned. zigzag antenna a travelling type of antenna, when properly designed produce very good axial beem of radiation with a very low side lobe [3].

In this work all the antennas stated above were designed and simulated using Computer Simulation Technology (CST) Microwave Studio suite.

1.2 Literature Review

Bibliography in the field of conformal antennas is still limited. Two relevant books were found: Design of Non-planar Microstrip Antennas and Transmission Lines [4] and the recent publication Conformal Array Antenna Theory and Design [5]. The former concentrates mainly in methods of analysis and resonance and coupling problems in conformal microstrip lines and antennas. It provides information regarding the polarization in cylindrical antennas.

The latter focuses mostly in conformal array configurations, although single antennas are also analysed. It includes abundant theory, simulations and measurements that make it a significant book in this field. In particular for this project, the book was very useful for a first insight into conformal antennas and, more in detail, for verification of the results and conclusions achieved through this project.

Most of the publications study methods of analysis suitable for non-planar structures. Different theoretical techniques are employed depending on the geometry although, in general, if the surface is electrically small almost any type of method can be used [5]. In many cases, the analysis of conformal antennas can be based on approximate techniques and when the antenna has very large radii of curvature, it may be often analysed as if it were planar [6]. Other important factor for the method selection is the accuracy and time consumption since, for instance, the cavity model is relatively fast but not as accurate as the full-wave analysis. As example, in [6] the spectral domain approach is used to study the radiation pattern and input impedance of a rectangular patch antenna on an infinitely long cylinder. The Fourier transform is applied to the fields and the Greens function of the structure is evaluated in the spectral domain. Then, the unknown current distribution of the patch, needed to obtain the radiation patterns, is calculated using the moment method. Other example of a different theoretical technique can be found in [7], where a wraparound patch mounted on a sphere is replaced by an equivalent current based on the cavity model theory. The accuracy of this method is confirmed in the publication by a more rigorous but complex theoretical approach based on the electric surface current model. These publications are interesting to learn about methods of analysis. However, the study of these techniques is not indispensable for the scope of this project since designs and analyses are carried out with EM simulators that use these methods.

Through the examples enclosed in most of the papers, characteristics of different types of conformal antennas can be studied. In the paper [8], the design and analysis spherical conformal array antenna was discussed and verified the realization of a spherical conformal array antenna with particular directivity through beam shaping to the corresponding linear array antenna. A pattern synthesis techniques and the far field radiation patterns were explained in the paper [1]. Regarding the design of this present microstrip spherical antenna array, reference [9] presents integration of a 2*2 planar microstrip array on a spherical surface and a comparison between planar array and orthogonal projected spherical array.

Power divider circuits are very important components in many microwave subsystems and circuits. These are very commonly used in mille meter wave circuits (antenna array feed networks, balanced mixers, amplifiers and phase shifters). The T-junction power divider is not matched at all ports, hence its a lossy divider and isolation between the output ports is also big problem. The resistive power divider is matched at all ports but isolation between output ports is still big issue. The Wilkinson divider [2] is such a microwave network, with satisfying lossless, all ports matched and isolation between output ports. that is, only reflected power from the output ports is dissipated. The design techniques of equal and unequal Wilkinson power dividers and their applications were explained in the papers [10, 11, 12, 13].

The UWB range released by Federal communications commission (FCC) in 2002 is 3.1GHz to 10.6GHz. Because of high bandwidth and advantages including small size, low complexity, ease of fabrication and low cost, these systems are mostly used in the ultra-wide band range.[14, 15, 16]. The simplest way to implementing planar forms of the antenna is using the microstrip feeding technology. Microstrip patch antenna in its very simplest form contains a ground plane on one side of dielectric substrate and radiating patch on other side. Different ground dimensions i.e. full ground, half ground, defective ground and n ground plane methods which is used for this purpose [17, 18, 19, 20]. The defective ground structure is control the EM wave propagation and excitation through substrate layer. Computer Simulation Technology(CST) is a dedicated tool for accurate and fast 3D EM simulator for high frequency problems [17]. Because of their features of light weight, low cost, nearly omni-directional radiation pattern and ease of fabrication, it is widely used in UWB applications.

Zigzag antennas are well known for its uni-directional radiation patterns. In his paper [21] Cumming studied the radiation properties of such an antenna at a single frequency. He made more elaborate experimental investigations about the properties of a balanced type of double zig-zag antenna. A more thorough investigation of the single zig-zag antenna has been necessary in connection with the building up of a radio telescope whose antenna assembly consists of a rectangular array of six monopole zig-zag antennas. For the satisfactory design of the telescope, a better understanding of the radiation properties, especially the half-power beam width, side lobe ratio, and the bandwidth of operation, has been necessary [22]. The traditional design of Zig-Zag antenna uses uniform element length and constant pitch profile [23, 24]. But when coming to practical approach it requires non uniform Zig-Zag structure, to satisfy the design limitations and to deduce the complexity and to get desired radiation patterns of antenna design. Referring to the standard geometry, the geometrical parameters of Zig-Zag structure are varied [25, 26] to get desired radiation characteristics.

1.3 Objectives

The main objectives of this thesis work are as follows:

- Design and analysis of a spherical microstrip antenna array using CST microwave studio suite.

- Design of a conventional Wilkinson equal and unequal power dividers using CST microwave studio suite.

- Design of a UWB antenna for high speed data rate applications using CST microwave studio suite.

- Design of Zigzag antenna for HF, VHF and UHF applications using CST microwave studio suite.

By the end of this thesis one can understand design of all above stated different type of antennas.

1.4 Thesis Organization

- This thesis work organised in seven chapters in chapter 2 gives fundamentals of microstrip antenna, feeding techniques to the feed antennas and bandwidth enhancement techniques.

- Chapter 3, discuss the conventional Wilkinson power divider. Even mode and odd node analysis of two-way equal Wilkinson power divider analysed and design parameters were presented. It also includes the design of equal and unequal power divisions and their analysis, implementation of proposed design with aid of CST microwave studio suite. Results of equal and unequal power divider were also discussed in this chapter.

- Chapter 4 mainly concentrated on designing of spherical microstrip antenna array. Geometry of the antenna explained. Simulation was carried out by CST microwave studio. At end of the chapter, results of the proposed antenna array has been discussed.

- Introduction of ultra-wide band antenna, applications and design parameters of the microstrip UWB antenna is presented in chapter 5. Simulation results of the designed antenna were also included in this chapter.

- Zigzag antennas are mostly used in the VHF and UHF range because of their uni-directional radiation pattern characteristics. In the chapter 6, designing and analysis of zigzag antenna was taken care and simulation is done using CST software, a powerful tool for high frequency electromagnetic simulator. Results of the designed antenna is discussed.

- Chapter 7 concludes the thesis work and future scope of the work is discussed.

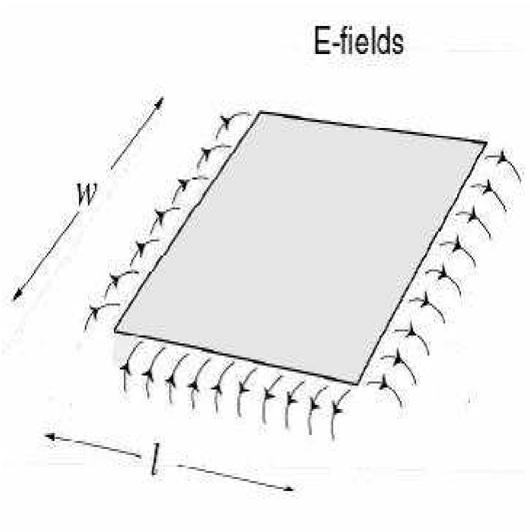
Chapter 2

Fundamentals of Microstrip Antennas

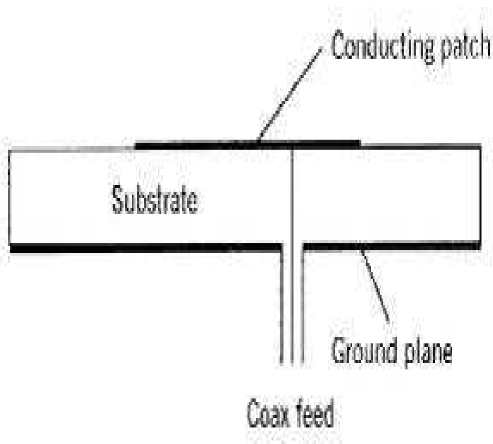
Only microstrip antennas will be considered for this project due to the fact that these are the most suitable type of antennas which might be conformed over a given surface of arbitrary shape. In addition, they have other advantages as low profile, moderate gain, easy of arraying, compatible with MMIC, light weight, low cost, etc. However, it must be mentioned some disadvantages like reduced bandwidth and relatively low radiation efficiency due to the surface wave excitation and losses from the conductor and the dielectric substrate.

Microstrip patch antennas consist of a thin metallic strip etched on a grounded dielectric substrate, as can be shown in Fig.2.1b, which shows a probe-fed microstrip patch antenna. The geometry of the patch can be almost any type of shape: square, rectangular, circular, triangular, etc. The properties of the substrate, such as thickness and relative permittivity, play an important role in the performance of the antenna.

The radiation from a microstrip patch antenna is equivalent to the radiation from two apertures, i.e. two equivalent magnetic currents with same direction. This equivalent model is the result of replacing the E-fields of the patch in Fig.2.1a by orthogonal magnetic currents. On the non-radiating edges the E-fields have opposite direction and, therefore, opposite magnetic currents that cancel each other.



(a) Microstrip patch antenna E-fields.



(b) Probe-fed microstrip patch antenna geometry.

Figure 2.1: Microstrip patch antenna E-field and Geometry.

2.1 Feeding Techniques

There are four fundamental techniques to feed a microstrip patch antenna [27]: edge feeding, probe feeding, aperture coupling and proximity coupling.

The first is one of the initial microstrip excitation techniques. In this method, the microstrip line is in direct contact with the patch, as shown in Fig.2.2a the best advantage of this feeding technique is the ease of manufacture since the microstrip line and patch can be etched on the same board. However, there is an important drawback which is the unwanted radiation from the feed that affects the radiation pattern of the antenna.

Probe feeding is a simple method where the inner conductor of a coaxial cable is extended through the ground plane and is connected to the patch, shown in Fig.2.2b. One advantage, unlike the method explained above, is the isolation of the feed from the radiating element via the ground plane. This feature minimizes the spurious radiation and makes it an efficient method since there is direct contact with the element. Nevertheless, there is still narrow bandwidth.

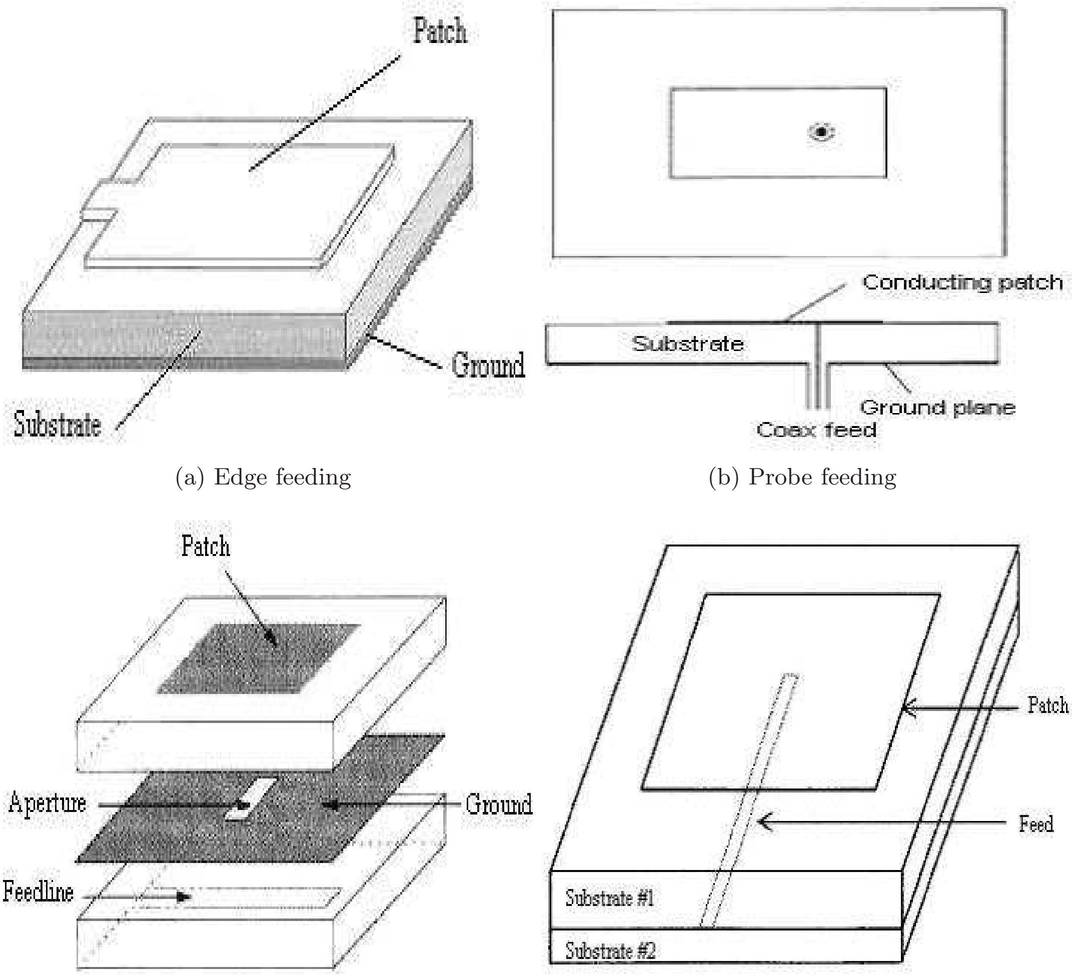
Next method to comment is aperture-coupling. It is the first non-contact mechanism introduced to improve the drawbacks of the direct feeding techniques: narrow bandwidth and surface waves. In Fig.2.2c is illustrated an example of this technique. The power from the feed is coupled through a slot in the ground plane which separates the substrates of the feed and the patch. This method simplifies the fabrication and allows optimization of the feed and antenna substrates independently.

The last method introduced in this appendix, shown in Fig.2.2d, is called proximity coupling. The microstrip line is located on the grounded substrate and the patch is etched on the top of the second substrate that is located above. The two substrates are placed in certain distance allowing power from the feed electromagnetically couple to the patch. This mechanism is capacitive in nature unlike direct contact techniques. Thus, the bandwidth usually is increased. The drawback is that this method produces high spurious feeding radiation since the feed and antenna layers are not fully independent.

2.2 Enhancing Bandwidth Techniques

Microstrip antennas have very narrow bandwidth, approximately up to 5%. Generally, to improve bandwidth one or more resonant antennas are added to the patch configuration. Some methods are introduced below.

Stacked micrsotrip patches, illustrated in Fig.2.3a are the most common procedure used to enhance the bandwidth of a microstrip antenna. It can



(a) Edge feeding (b) Probe feeding

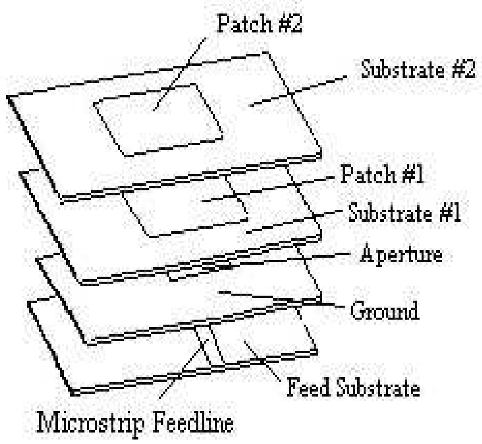
(c) Aperture coupling (d) Proximity coupling

Figure 2.2: Microstrip patch antenna feeding techniques

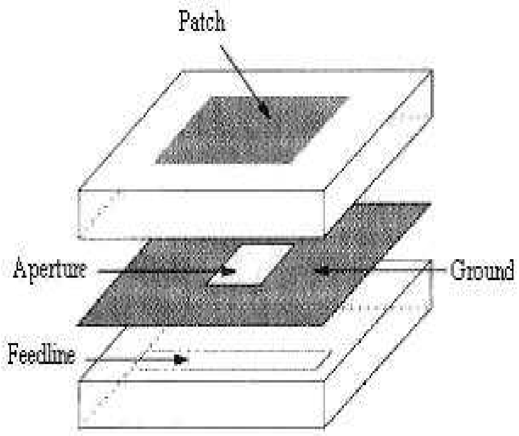
achieve bandwidths of almost 30%. These antennas are relatively easy to design and can be easily accommodated into an array environment.

Increasing the size of the slot of an aperture-coupled patch is a simple way of increasing the bandwidth, as in Fig.2.3b. This will ensure that the power is coupled to the patch located on a thick dielectric substrate, reaching bandwidths of 40%. However, this technique shows two problems. Firstly, the front to back radiation ratio tends to be poor, and secondly, the large slot can cause deformation of the radiation pattern.

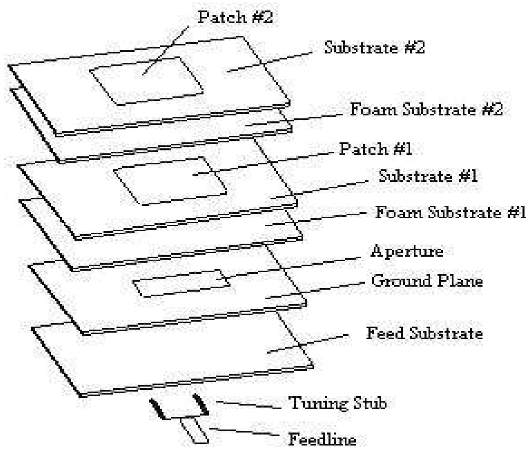
The ultimate wideband microstrip patch antennas are ASP (aperture-stacked patch) and consist of a large slot and two directive patches, as can be seen in Fig.2.3c The front to back ration is not as poor as the technique explained above because of the additional directive patch. They have attractive characteristics that make them suitable for wideband applications as good impedance and gain bandwidth, good polarization control, compactness, relatively simple development and, despite its electrical thickness, it does not suffer from surface wave problems since the surface wave power is coupled to the adjacent patches and radiated into space.



(a) Stacked microstrip patches



(b) Large slot in aperture-coupled patches



(c) Large slot in aperture-stacked patches

Figure 2.3: Microstrip patch antenna enhancing bandwidth techniques

Chapter 3

Wilkinson power dividers and Design

The T-junction power divider is not matched at all ports, hence its a lossy divider and isolation between the output ports is also big problem. The resistive power divider is matched at all ports but isolation between output ports is still big issue. The Wilkinson divider is such a microwave network, with satisfying lossless, all ports matched and isolation between output ports. The Wilkinson divider is made with stripline form or microstrip line as shown in 3.1a. due to its planar nature, its very easy to fabricate. Arbitrary power divisions can be possible with this divider, but we will first derive equations for the designing of equal power divisions. 3.1a showing microstrip line form of power divider and 3.1b is showing the corresponding transmission line circuit. reducing the circuit by symmetric and antisymmetric i.e. even mode and odd mode analysis at the output ports.

3.1 Transmission line circuit

The Wilkinson divider is a three-port circuit that is all output nports are matched hence lossless. Input power can be divide into two or more that is arbitrary power divisions is possible in-phase signals. For a 2:1 Wilkinson power divider using $\frac{\lambda}{4}$ transmission line circuits impedance transformers having a characteristic impedance of $\sqrt{2}Z_0$ and a isolation resistor of $2Z_0$ with all three ports matched, isolation between the output ports is achieved

1. The design of an equal-divide(3 dB) Wilkinson is made with stripline or microstrip form; all designs considered in this thesis are microstrip, as shown below in Fig.3.1 The equivalent transmission line circuit is shown in Fig.3.1

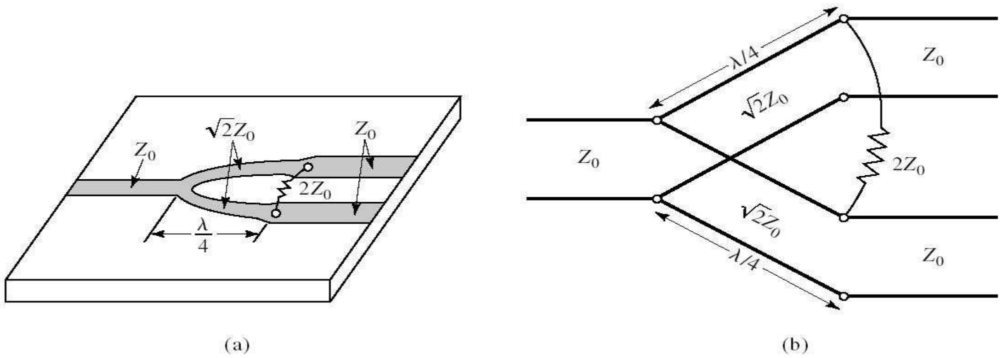


Figure 3.1: The Wilkinson power divider taken from 2. (a) An equal-split Wilkinson power divider in microstrip form. (b) Equivalent transmission line circuit.

3.2 Derivation of scattering parameters

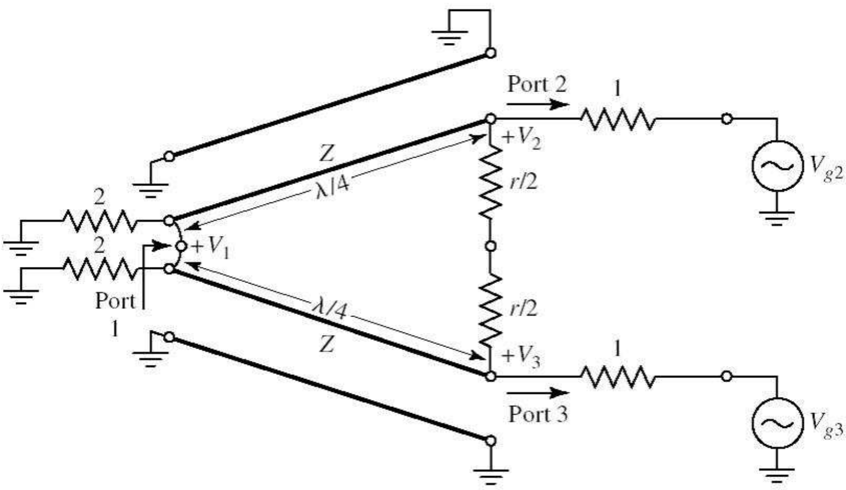


Figure 3.2: The Wilkinson power divider circuit taken from [2] in normalized and symmetric form.

The S-parameter matrix for the Wilkinson power divider can be found using even-odd mode analysis which uses circuit symmetry and superposition [2]. As a first step the circuit in Fig.3.1(b) is redrawn with all impedances normalized to the character impedance Zo and redrawn as shown in Fig.3.2 There is no current flow between the $\frac{r}{2}$ resistors or the short circuit between the inputs of the two transmission lines at port 1. Therefore the circuit above can be bisected and separated into two systems, even and odd (Fig.3.3(a) and (b) respectively). Each system can be then analysed separately.

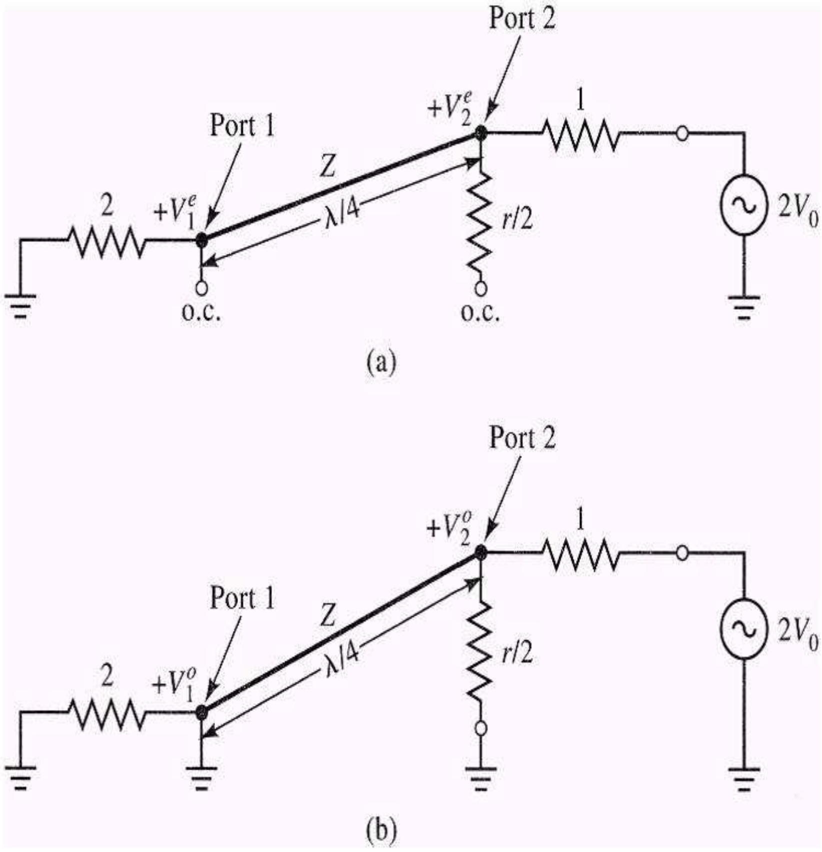


Figure 3.3: Bisection of the circuit of Fig 3.2 taken from [2]. (a) Even-mode excitation. (b) Odd-mode excitation.

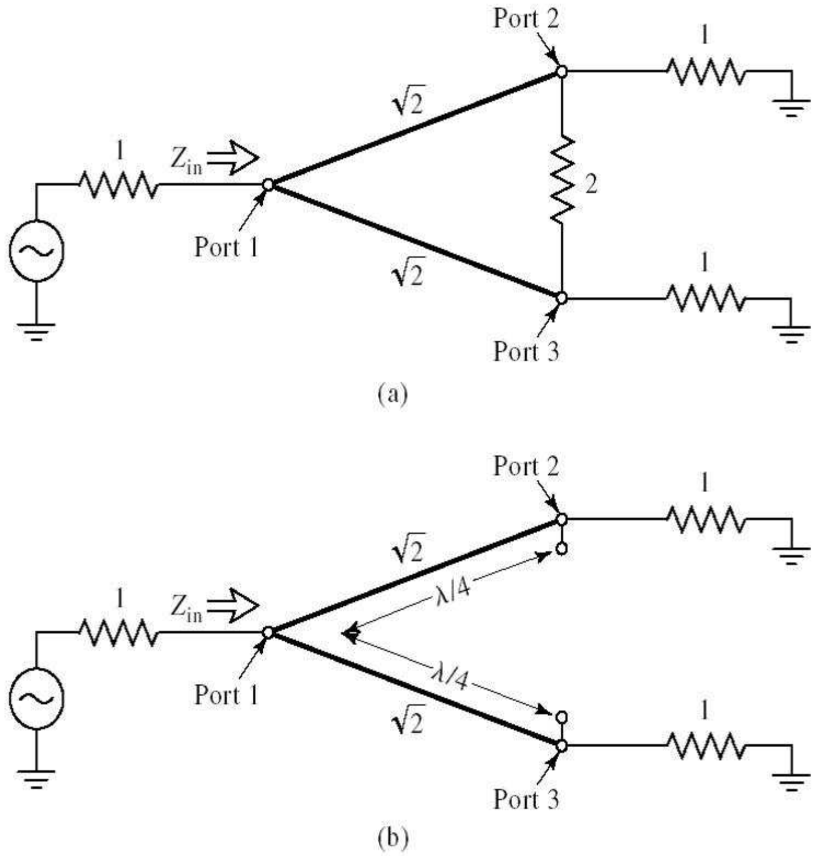


Figure 3.4: Analysis of the Wilkinson divider (from [2] to find S11. (a) Terminated Wilkinson divider. (b) Bisection of the circuit in (a).

Even mode Analysis:

First the input impedance at Port 2 of the circuit in Fig.3.3 (a) is checked where $Z = \sqrt{2}$

${Z_{in}}^e = \dfrac{Z^2}{2} \Rightarrow Z = \sqrt{2}$ for matching$(S_{22,e} = 0, S_{33,e} = 0))$

Then voltage at port 2 and port 1 are found

${v^e}_2 = jv^+(1 - \Gamma) = v_0$

${v^e}_1 = v^+(1 + \Gamma) = jv_0 \dfrac{\Gamma + 1}{\Gamma - 1}$

$\Gamma = \dfrac{2 - \sqrt{2}}{2 + \sqrt{2}}$

${v^e}_1 = -jv_0\sqrt{2}$

Odd mode Analysis:

The input impedance at port 2 of fig 6 is found again as

$Z^0{}_{in} = \frac{\sqrt{2}^2}{2}$ (matched)

Voltage at port 2 and port 1 are

$v^0{}_2 = v_0$

$v^0{}_1 = 0$ (virtual ground)

The S_{11} in the circuit shown below in Fig.3.3 (a) and its bisection (b) are used.

When ports 2 and 3 are terminated with matched loads, there is no current flow through the normalized isolation resistor and it can be removed. The input impedance at port 1 is then

$Z^0{}_{in} = \frac{\sqrt{2}^2}{2} = 1$

3.2.1 summary of scattering parameters

The S-parameters are thus:

$S_{11} = 0$ inport is matched.

$S_{22} = S_33 = 0$ output matched for even/odd modes.

$S_{12} = S_{21} = \frac{v^e{}_1 + v^o{}_1}{v^e{}_2 + v^o{}_2} = -\frac{j}{\sqrt{2}}$ symmetry due to reciprocity.

$S_{13} = S_{31} = -\frac{j}{\sqrt{2}}$ symmetry of 2 and 3.

$S_{23} = S_{32} = 0$ Due to short or open at bisection.

Therefore, the S-matrix can be written as:

$$S = -\frac{1}{\sqrt{2}} \begin{bmatrix} 0 & j & j \\ j & 0 & 0 \\ j & 0 & 0 \end{bmatrix}$$

3.2.2 Figure of merit

The performance of the Wilkinson divider/coupler is commonly evaluated by the following Figures of merit:

$RL_1[dB] = -20log|S_{11}|$ Return loss at port 1.

$RL_2[dB] = -20log|S_{22}|$ Return loss at port 2.

$CP_{12}[dB] = -20log|S_{12}|$ Coupling between port 1 and port 2.

$IL_{23}[dB] = -20log|S_{23}|$ Isolation between port 2 and port 3.

3.3 Frequency response of an equal divider

The frequency response of the equal-divide Wilkinson power divider is shown in Fig.3.5 below. The figures of merit discussed in the previous section are shown over the band from 0.5 to 1 GHz, return loss, isolation, and coupling.

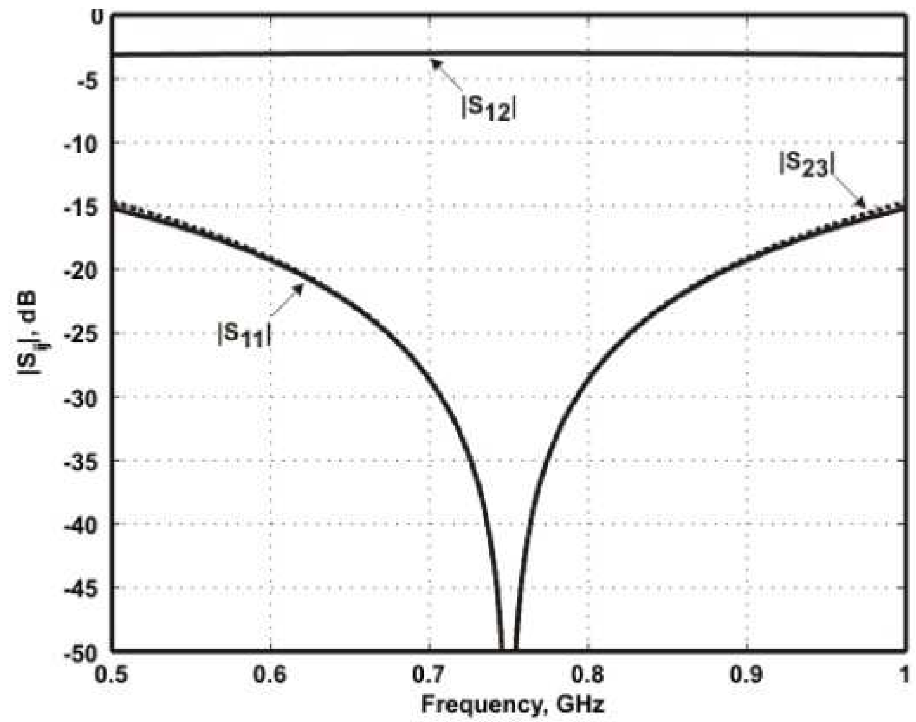


Figure 3.5: Frequency response of an equal-divide Wilkinson divider.

3.4 Design of Wilkinson equal power divider

Design for centre frequency of 5.35 GHz the quarter wavelength of the strip line $\frac{\lambda}{4} = 7.5mm$ and requires the isolation resistor to be $2Z_0 = 100\Omega$ and the impedance of the quarter-lambda transmission line split section to be $\sqrt{2}Z_0 = 70.7\omega$ is shown in fig.3.6. FR-4 material with relative permittivity 4.3 and loss tangent 0.002 used as a substrate material and PEC material was used for ground and stripline design. The parameters of the design were listed in table 3.1.

Sr.No	Description	value in mm
1	Substrate thickness	1.6mm
2	Ground thickness	0.05mm
3	Width of the 50ω line	2.6mm
4	Width of the 70.7ω line	1.6mm

Table 3.1: Design parameters of 2:1 equal Wilkinson power divider.

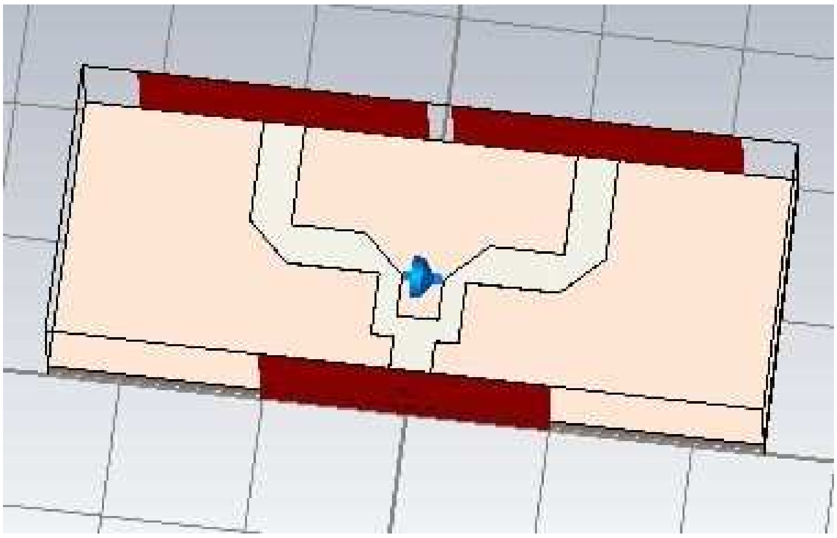


Figure 3.6: 2:1 equal Wilkinson power divider.

3.4.1 Simulation results of equal wilkiinson power divider

The simulation was performed using CST microwave studio suite 2014. The S-parameter plot of the design shown in fig 3.7. From S-parameter plot it is shown that S_{11} is has least value at operating frequency of 5.35 GHz and its value is -21.21dB i.e. the return loss of the Wilkinson equal power divider is very less at operating frequency. From fig 3.7 it is also clear that the output ports were isolated. There is -3.5dB coupling between input and outputs.

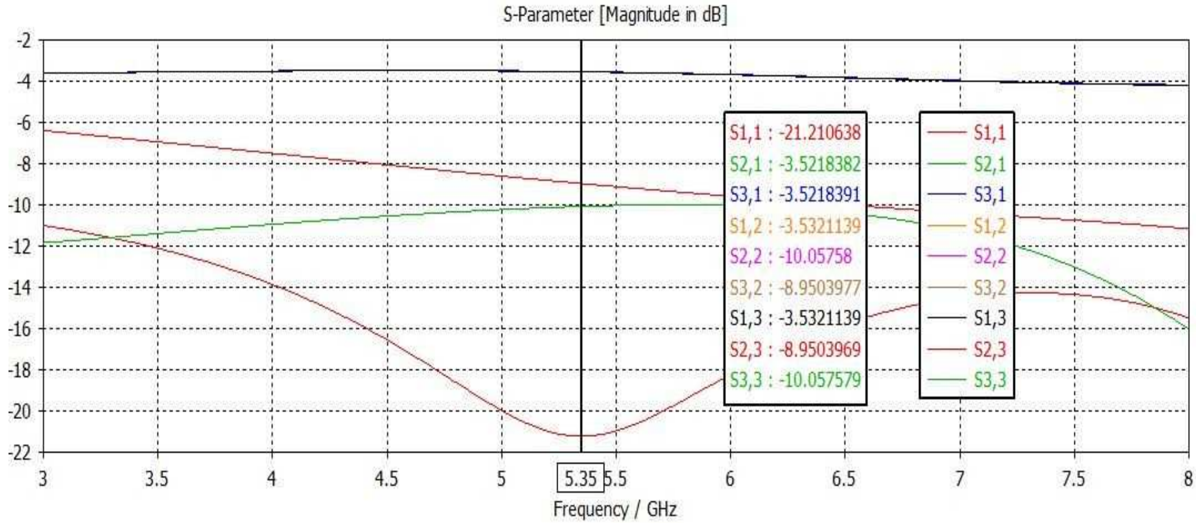


Figure 3.7: S-parameter plot of 2:1 equal Wilkinson power divider.

Adding two such above designs and we can form a 4: 1 equal Wilkinson power divider. In fig 3.8 the design shown and fig 3.9 is showing simulation result of the equal 4:1 Wilkinson power divider. Return loss of the design is below the satisfactory value and coupling between input and output equal for all ports.

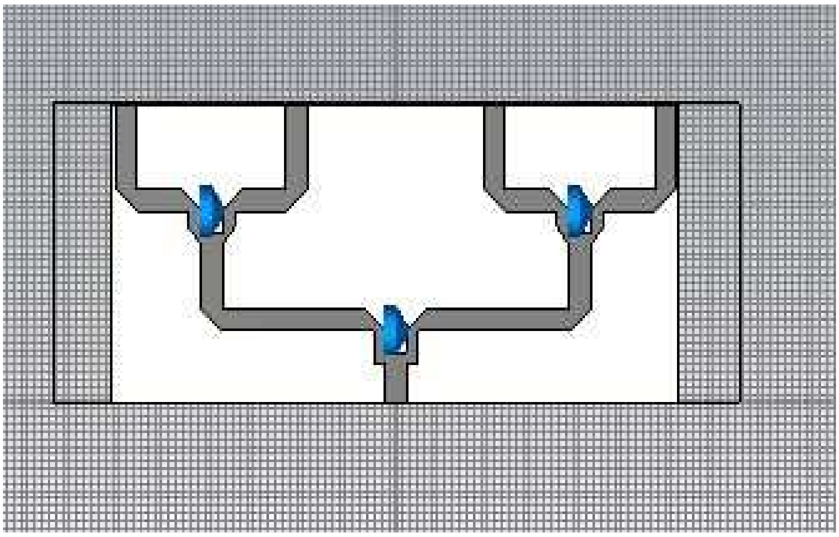


Figure 3.8: 4:1 equal Wilkinson power divider.

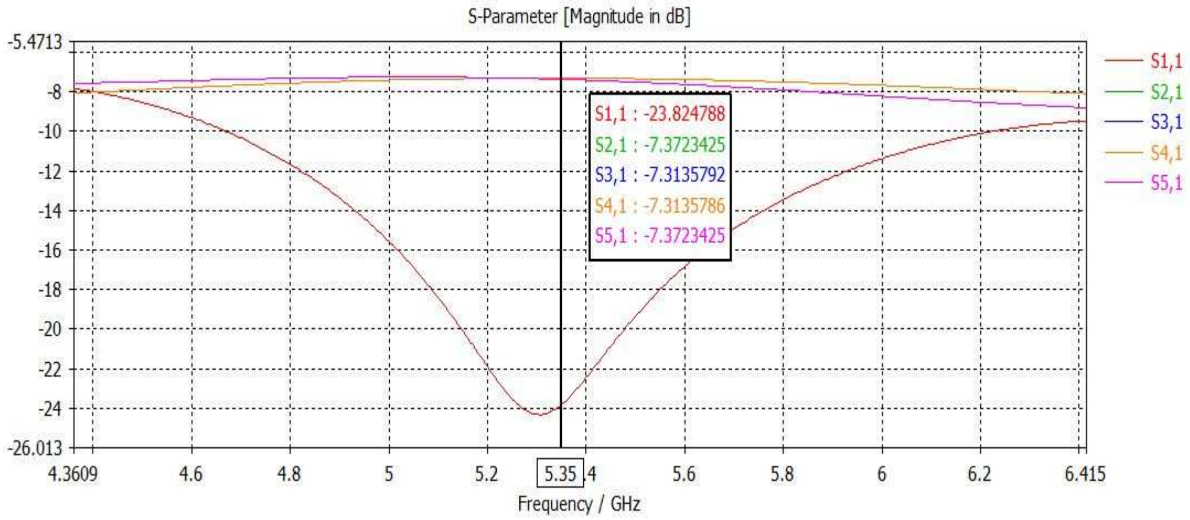


Figure 3.9: S-parameter plot of 4:1 equal Wilkinson power divider.

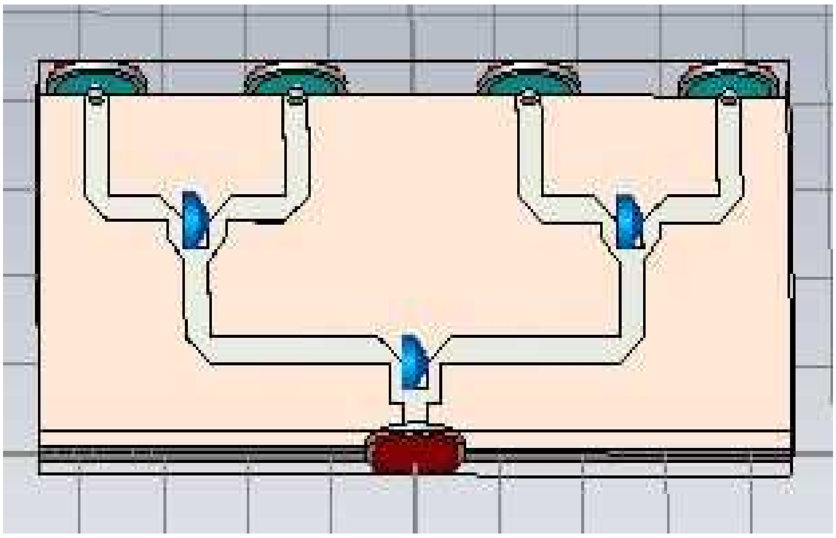


Figure 3.10: Power divider with coaxial line feeding.

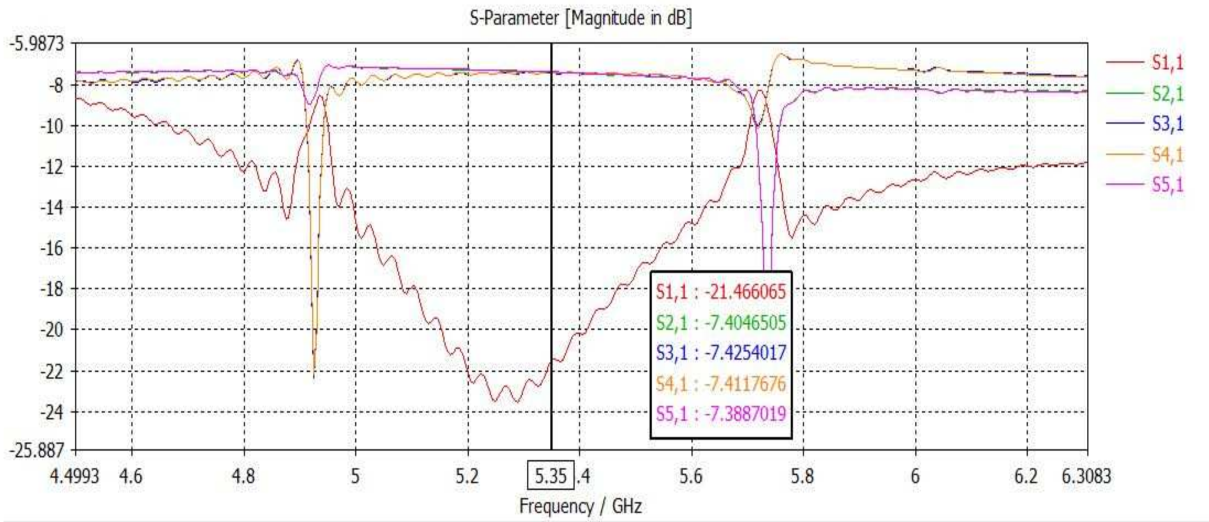


Figure 3.11: S-parameter plot of coaxial line feeding power divider.

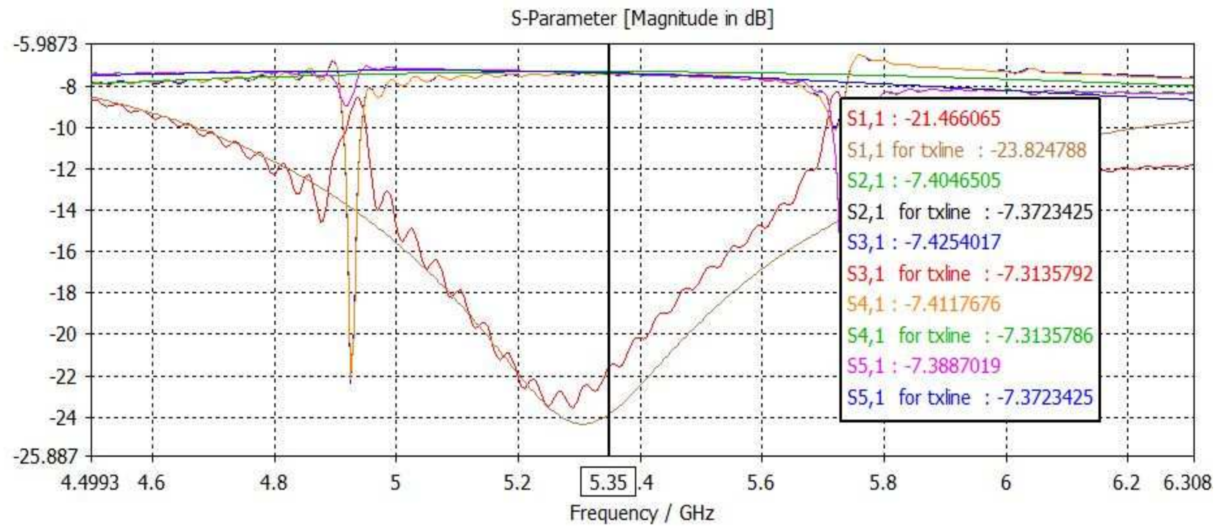


Figure 3.12: S-parameter comparison between coaxial line and transmission line feeding.

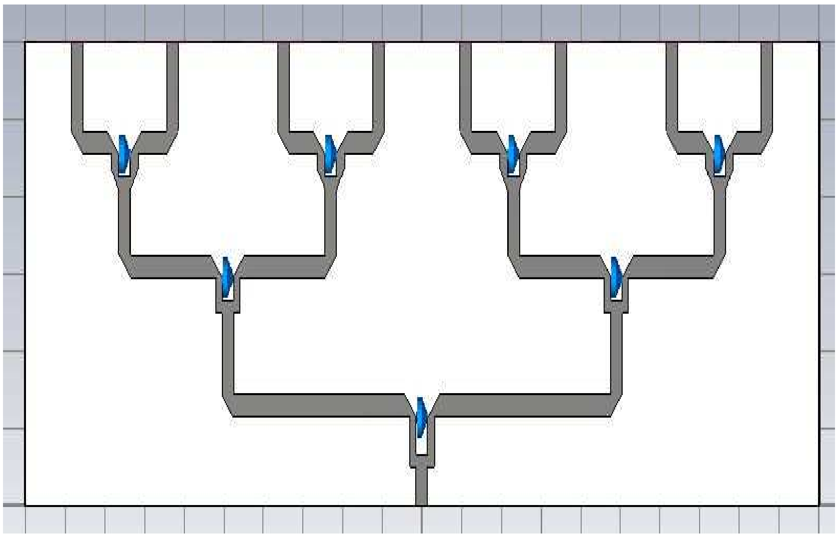


Figure 3.13: 8:1 equal Wilkinson power divider.

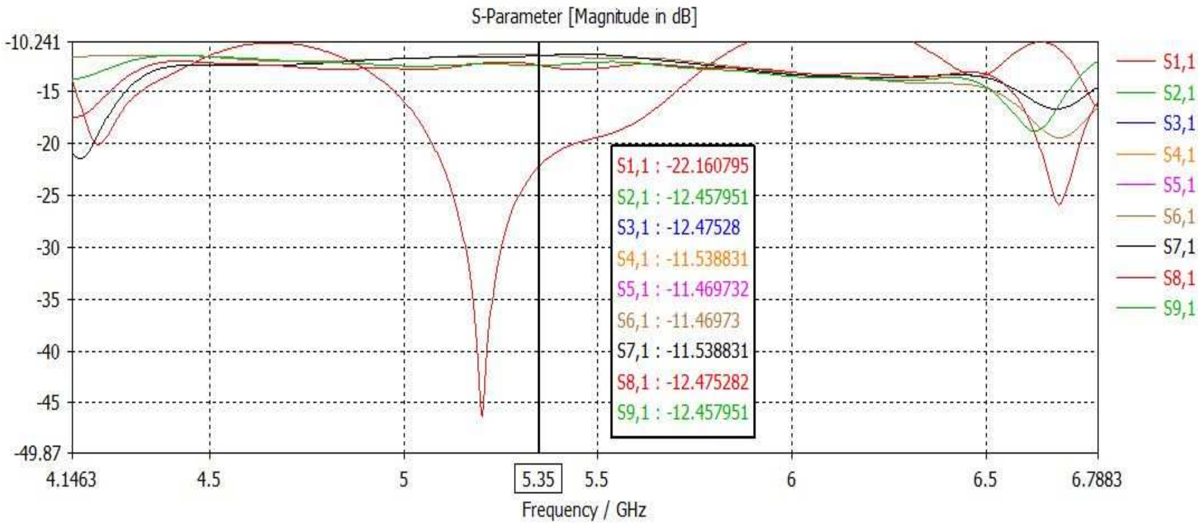


Figure 3.14: S-parameter 8:1 equal Wilkinson power divider.

3.5 Design of Wilkinson Unequal power divider

All the above power dividers are designed for equal splitting and for practical purposes unequal powers also needed for different applications. Wilkinson-type dividers can also be made with unequal power divisions. A strip line version is shown in fig3.15. If the power division ratios between ports 2 and 3 is $K^2 = \frac{P3}{P2}$, then the following design equations apply:

$$Z_{03} = Z_0\sqrt{\frac{1+K^2}{K^3}}$$

$$Z_{02} = K^2 Z_{03} = Z_0 \sqrt{K(1+K^2)}$$

$$R = Z_0(1 + \frac{1}{K})$$

Note that the above results deduce to the equal-divide case for K =1. Also observe that the output lines are matched to the impedances $R_2 = Z_0 K$ and $R_3 = \frac{Z_0}{K}$, as opposed to the impedance Z_0; matching transformers can be used to transform these output impedances.

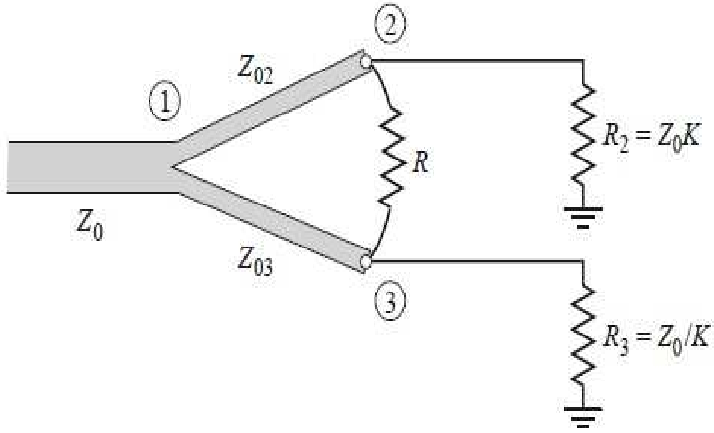


Figure 3.15: A Wilkinson power divider in microstrip form having unequal power division.

3.5.1 Simulation and Results for unequal power divider

Fig 3.16 shows the design of the 4:1 unequal power divider, in two arm impedances of the stripline were chosen such 1:2 ratio. To select arm impedances in the desired ratio, the arm widths of the striplines to be designed properly. The two different arm widths are 0.65mm and 2.8mm, rest of all the parameters are same as the above designs and transmission line feeding was given to the circuit. Using CST microwave studio suite 2014, the design was simulated and the S-parameter plot of the unequal power divider shown in below fig 3.17. From the S-parameter plot it is observed that return loss is below the considerable value for power dividers at the operating frequency of 5.35Ghz and the output power ratios are also showing unequal.

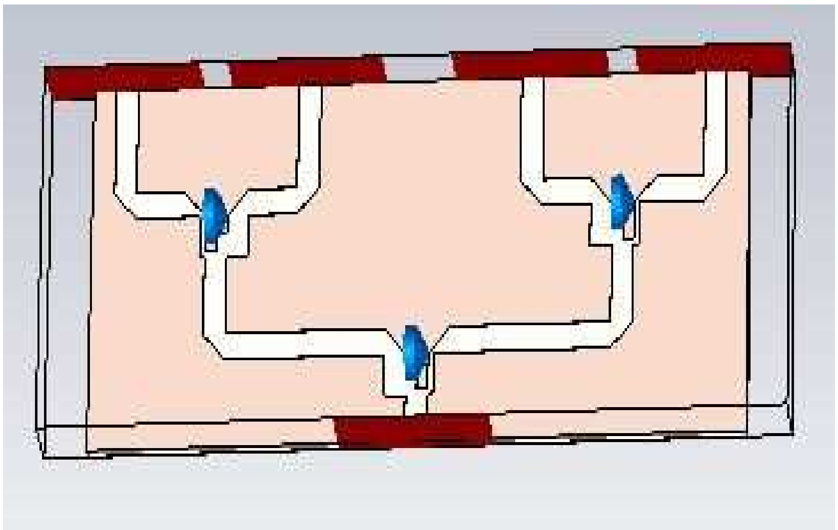


Figure 3.16: 4:1 Wilkinson Unequal power divider.

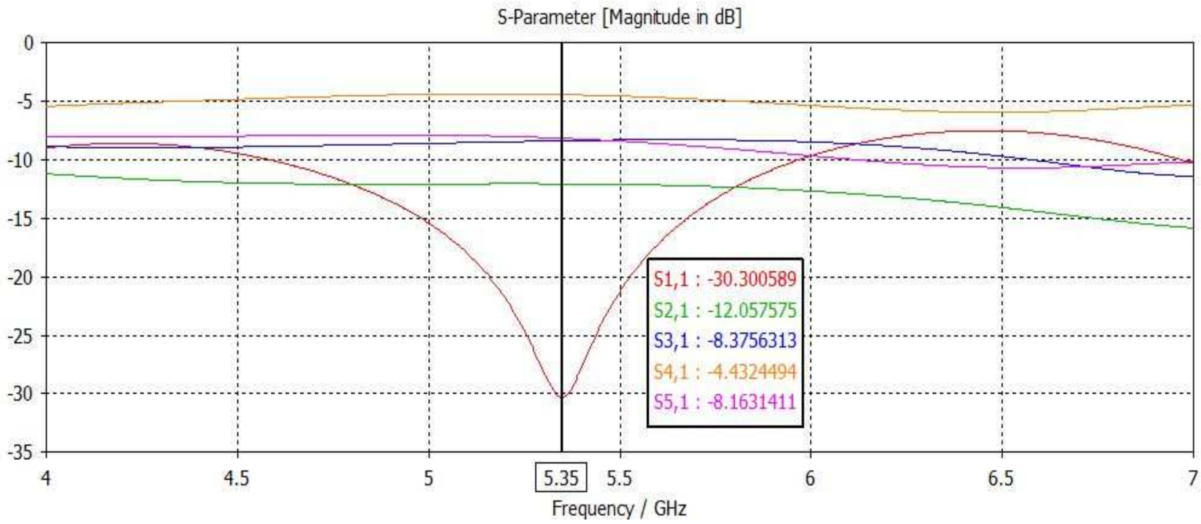


Figure 3.17: S parameter for Wilkinson 4:1 Unequal power divider.

Chapter 4

Microstrip Spherical Antenna Array Design

An antenna array radiation pattern synthesis has two main concerns. The first one is compulsory to govern the complex pattern of the array elements. Then to synthesize the desired pattern, the current excitations need to be evaluated. To improve the accuracy of the calculated current excitations, complex patterns of the array elements can be determined from the array analysis in a full-wave electromagnetic simulator, such as CST Microwave studio, since this software is able to account for the mutual coupling among array elements and the truncation of the ground layer and the diffraction at the edges of the conducting surfaces; these last two effects are present, for example, in hemispherical microstrip arrays. Hence, the first step of the proposed pattern synthesis technique comprises the placement of the spherical microstrip antennas and the array analysis in a full-wave electromagnetic simulator.

In this dissertation sixteen similar rectangular micro strip patch antennas mounted on a spherical surface in phi plane. Rectangular microstrip patch antenna was designed to operate at a frequency of 5.35GHz. S parameter of the design shown and all the elements are showing below -10dB return loss. Polar plot and Cartesian plots of different Phi plane are shown, though directivity is less compared to single element, the radiation properties and patterns were improved. High frequency electromagnetic simulation software CST Microwave studio suite is used to design and simulate the proposed antenna.

4.1 Antenna Geometry

A rectangular patch antenna has dimensions $l*w = 16.58*21.80mm$ with material PEC, here l is radiating edge and is equal to $\frac{\lambda}{2}$ for operating frequency of 5.35Ghz. Rectangular patch was placed on substrate of thickness 1.66mm and relative permittivity $\epsilon_r = 2.5$ and ground plane of thickness 0.05mm with PEC material is extruded from substrate. The rectangular patch is shown in fig.4.1. A transmission line feeding is used to providing feed to the element.

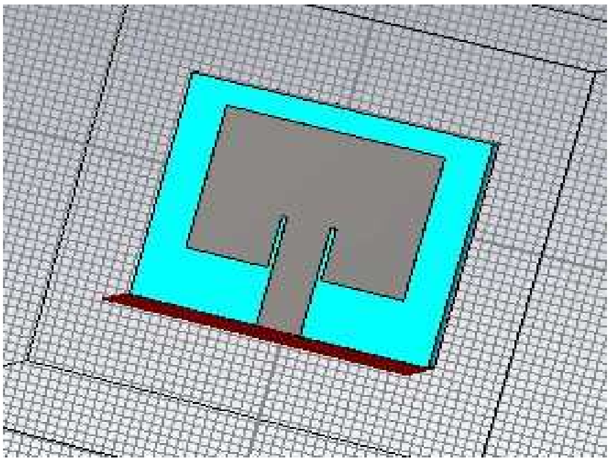


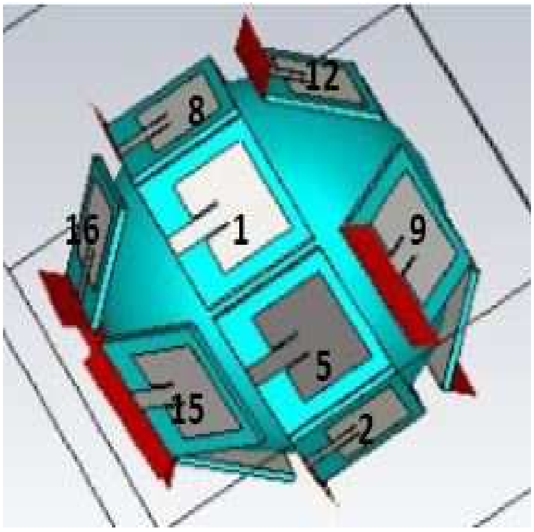
Figure 4.1: Rectangular patch antenna

Fig 4.2 shows the design and geometry of microstrip spherical antenna array. The designed single antenna has mounted on a spherical surface with radius of 38mm and material with relative permittivity $\epsilon_r = 2.5$. 4 similar antennas had taken and mounted on spherical surface on Phi plane at $\phi = 0^0, 90^0, 180^0, 270^0$ each, and single elements have been placed at $\phi = 45^0, 135^0, 225^0, 315^0$ and $\theta = 0^0$

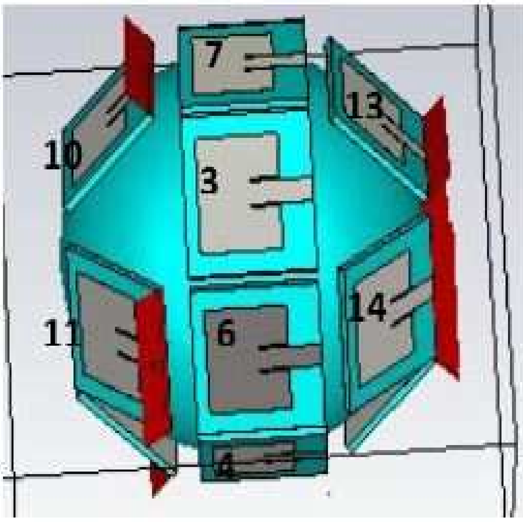
Elements 1 to 8 were mounted at $\theta = 90^0$ with $\phi = 45^0$ variation,

Elements 7, 10, 13 are at $\phi = 0^0$, and $\theta = 90^0, 135^0, 45^0$ respectively,

Elements 6, 11, 14 are at $\phi = 90^0$, and $\theta = 90^0, 135^0, 45^0$ respectively,
Elements 5, 9, 15 are at $\phi = 180^0$, and $\theta = 90^0, 135^0, 45^0$ respectively,
Elements 8, 12, 16 are at $\phi = 270^0$, and $\theta = 90^0, 135^0, 45^0$ respectively,
Elements at $\phi = 0^0, 180^0$ form a circle and elements at $\phi = 90^0, 270^0$ form another circle.



(a) Front view

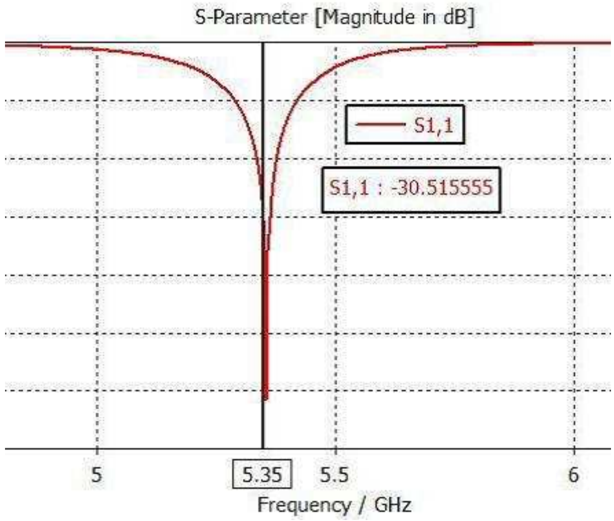


(b) Back view

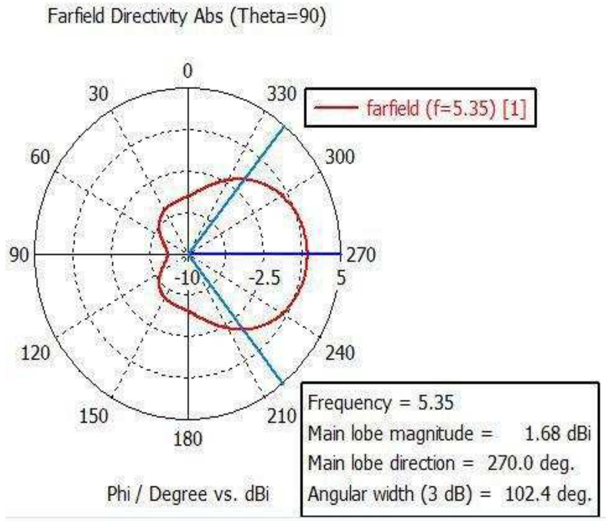
Figure 4.2: Geometry of Microstrip spherical antenna array

4.2 Simulation and Results for spherical array

The simulation was carried out by a high frequency simulation tool CST microwave studio suite. Fig4.3 shows the return loss plot and radiation pattern of a single microstrip antenna. In Fig4.4 the return loss plot of the proposed design shown and it is observed that all the elements are satisfying minimum value i.e. < -10dB at a frequency of 5.35GHz.



(a) Return loss



(b) Polar plot

Figure 4.3: Simulation results of single microstrip patch antenna

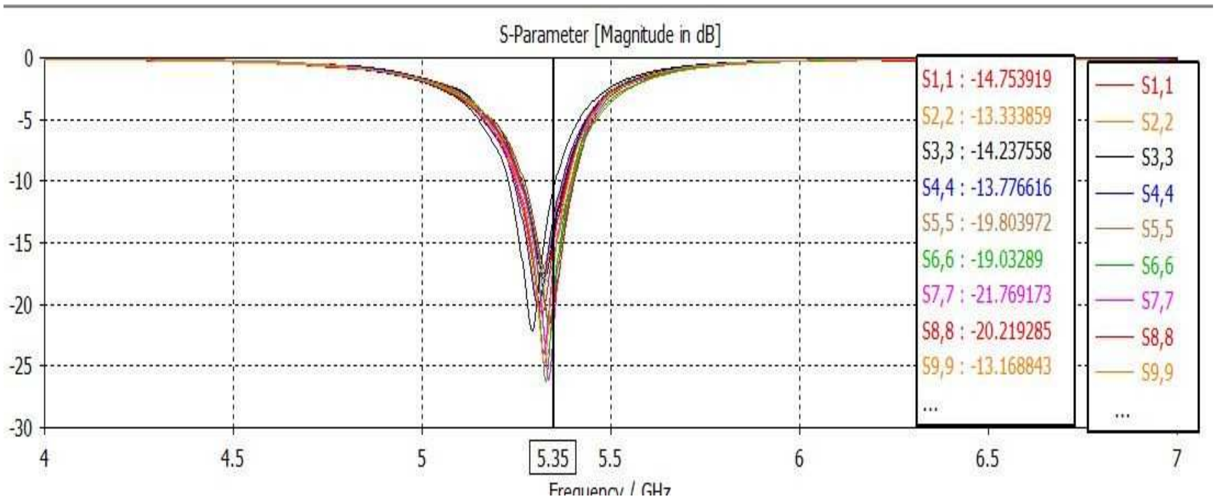
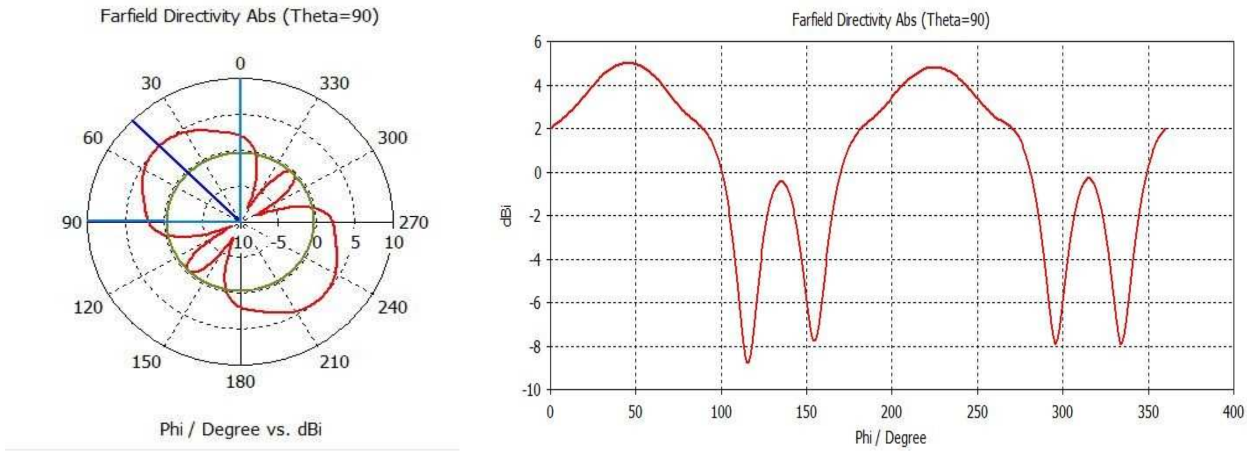


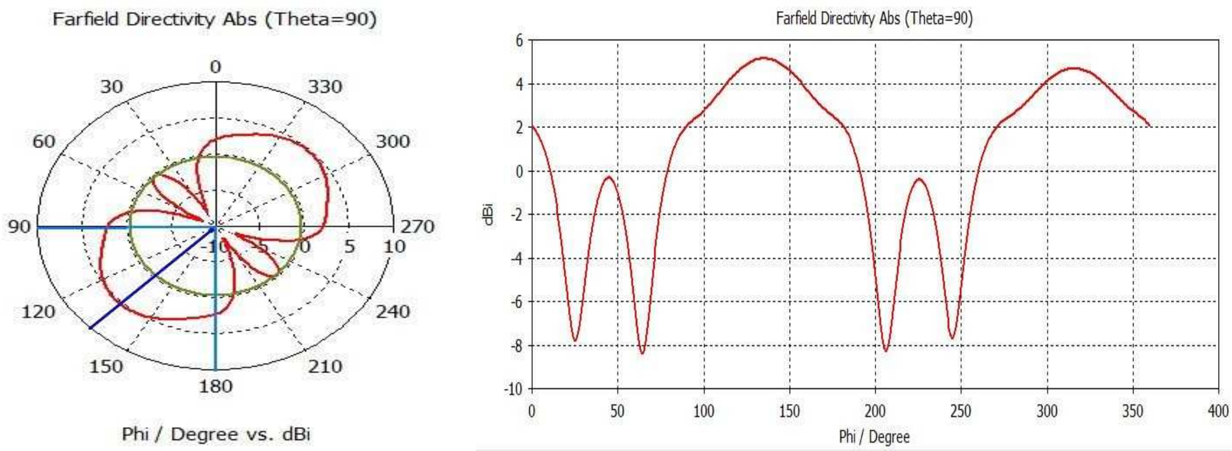
Figure 4.4: Frequency vs return loss plot of the microstrip spherical antenna array.

The radiation patterns polar plot and Cartesian plots are shown in fig below. Fig 4.5 shows the radiation plots of the antenna when elements 5, 7, 9, 10, 13, 15 i.e. elements at $\phi = 0^0$ and 180^0 were excited. Fig 4.6 shows the radiation plots of the antenna when elements 6, 8, 11, 12, 14, 16 i.e. elements at $\phi = 90^0$ and 270^0 were excited. Fig 4.7 shows the radiation plots of the antenna when all phi plane elements were excited. All the radiation patterns shown are giving beam shape pattern. Using post processing property of the CST microwave studio software one can perform the excitation of individual elements as well the selected elements and can combine the far-field properties of the selected elements.



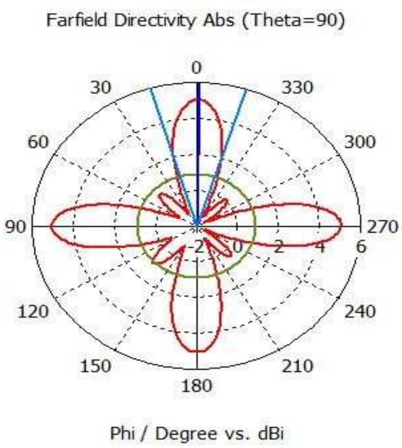
(a) Polar plot (b) Cartesian plot

Figure 4.5: Combined radiation patterns when element 5, 7, 9, 10, 13, 15 were excited.

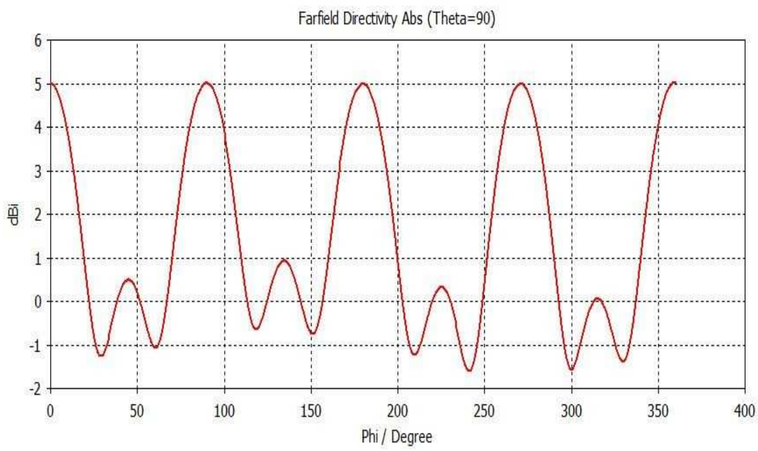


(a) Polar plot (b) Cartesian plot

Figure 4.6: combined radiation patterns when element 6, 8, 11, 12, 14, 16 were excited..



(a) Polar plot



(b) Cartesian plot

Figure 4.7: Combined radiation patterns when all the elements phi plane elements were excited.

Chapter 5

Ultra Wide Band Antenna Design

UWB range covers 3.1GHz-10.6GHz is released by FCC in 2002. From then on, the ultra-wideband (UWB) systems have attached much attention recently because of its advantages including high speed data, small size, low cost, low complexity. As the important part of the UWB systems, the antenna has received increased attention due to its impedance bandwidth, simple structure and Omni-directional radiation pattern. The simplest way to implementing planar forms of the antenna is using the micro strip feeding technology. Micro strip antenna in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side of the substrate. Defected Ground Structure is one of the methods which is used for this purpose. CST MICROWAVE STUDIO is a specialized tool for the fast and accurate 3D EM simulation of high frequency problems used to simulate the proposed antenna.

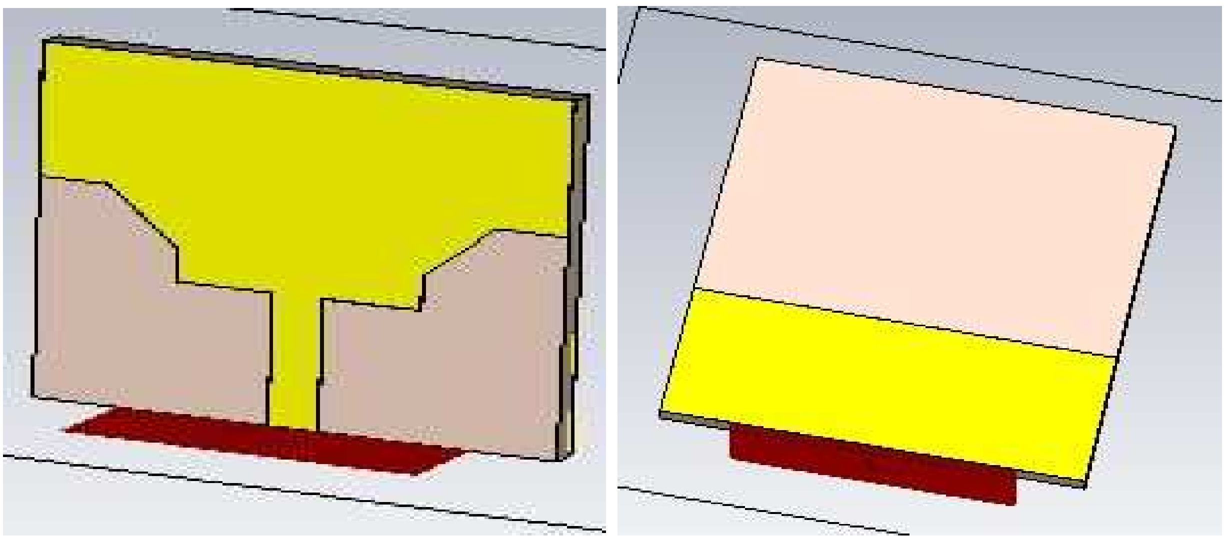
5.1 UWB Antenna Design Parameters

Microstrip antenna in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side of the substrate. Defected Ground Structure is one of the methods which is used to reduce the antenna size. In this paper a FR4 material with $\epsilon_r = 4.3$ is

Sr.No	Description	value in mm
1	Antenna length	30
2	Antenna width	32
3	Width of the ground plane	10
4	Substrate thickness	1.59
5	Feed size	2.9

Table 5.1: Antenna parameters

used as substrate material and copper material used as radiating element and ground. Optimised antenna parameter mentioned in below Table5.1.
In this paper with ground plane, without ground plane and a defective ground structure were analysed to get desired operating UWB range frequency. Defective ground structure with width 10mm, length 30mm and thickness 0.035mm giving the best performance. A 50Ω microstrip line used to providing feed to antenna, this made up of copper with thickness 0.035mm and width of the line mentioned in the table. Fig 6.2. shows the front and back view of CST design of the proposed antenna.



(a) Front view

(b) Back view

Figure 5.1: CST Design models of UWB Antenna

5.2 Simulation and Results

Return loss shown in fig 5.2 and fig 5.3 below -10dB in the entire UWB range (2.6GHz 10.3GHz) and minimum value of -35dB found at a frequency 3.298GHz is achieved. The radiation pattern has Broad side radiation pattern in the E-plane and Omni directional pattern in the H-plane. Gain is varying from 1.913dB to 4.248dB and maximum at 10.3GHz. The return loss plot and radiation plots are shown in below Fig 5.4.

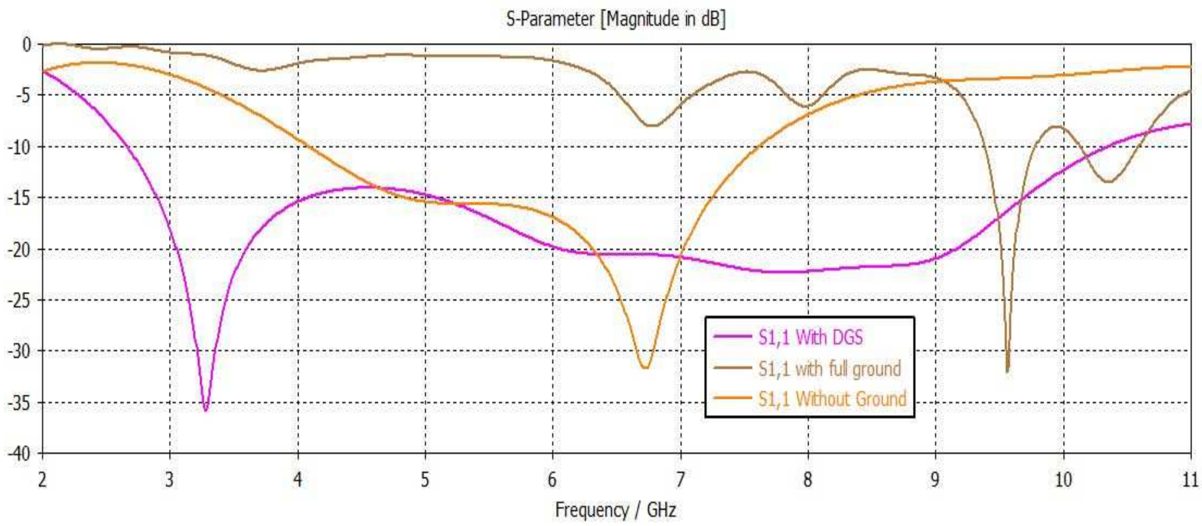


Figure 5.2: Return loss plot varying with ground

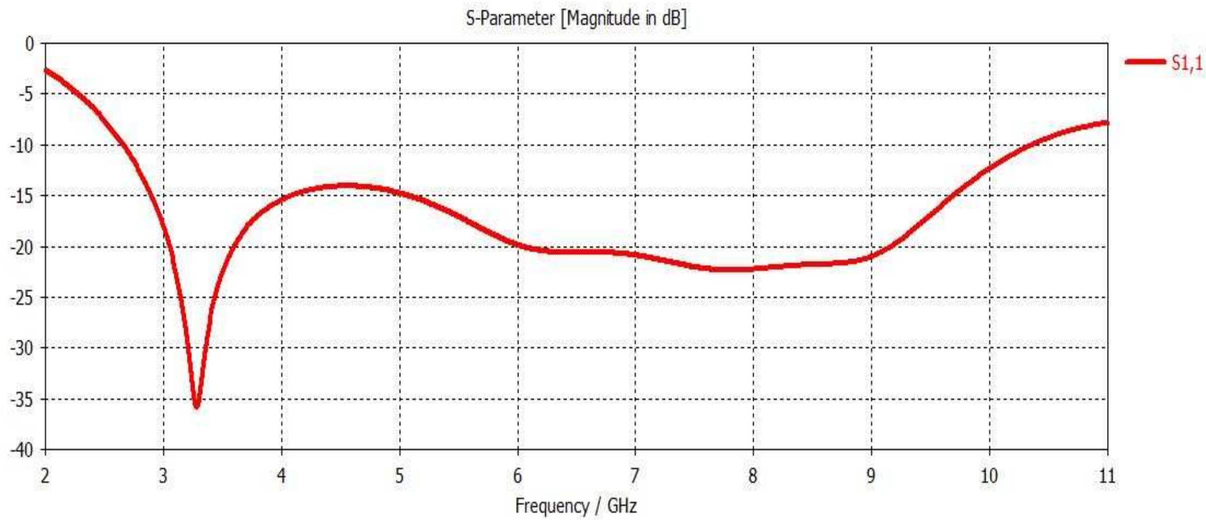
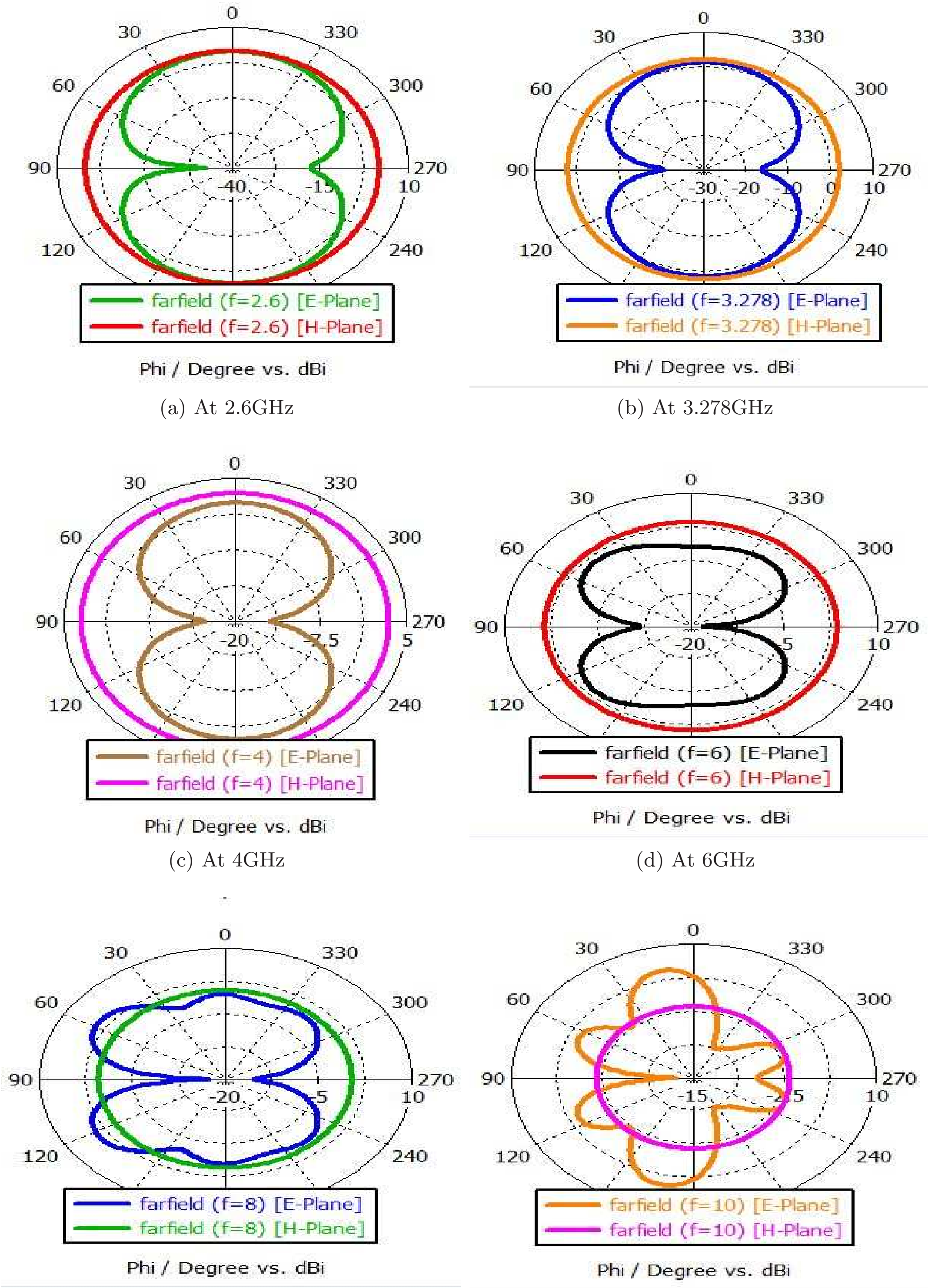


Figure 5.3: Return loss plot with defective ground



(a) At 2.6GHz

(b) At 3.278GHz

(c) At 4GHz

(d) At 6GHz

(e) At 8GHz

(f) At 10.3GHz

Figure 5.4: Radiation patterns of UWB antenna at different frequencies.

Chapter 6

Zigzag Antenna Design

Zigzag antennas are of great practical importance in high frequency, very high frequency, and ultra-high frequency communications. Zigzag antennas are used in applications where unidirectional radiation pattern is preferred. It has characteristics such as high gain, large bandwidth, and low cost. This antenna design is used where a wide range of frequencies is needed with high gain and directionality. This is a special type of traveling-wave antenna which, when properly designed, produces a strong axial beam of radiation with a very low side lobe [3].

This antenna is strongly related to the helical antenna but importantly the planar nature of the Zigzag wire structure make it easier and faster to fabricate than helix. Thus, the zigzag antenna is Very convenient geometry to verify the small antenna design procedure [26].

Radio telescope is an astronomical instrument consisting of a radio receiver and an antenna system that is used to detect radio-frequency radiation emitted by extra-terrestrial sources. The radio telescope made up with the zigzags operates at 300MHz. But at 300MHz, the physical dimensions of the antenna become unwieldy for elaborate pattern studies. From the principle of model measurement [28] it is known that the radiation pattern of the antenna at 300MHz will be the same as that at 3600MHz, provided that the physical dimensions of the antenna are scaled up by a factor of 12. The choice of

3600MHz as the frequency of measurement is found to be advantageous both electrically and mechanically.

6.1 Zigzag Antenna Design

One of the configurations of zigzag antennas that has been frequently investigated, and extensively used, is the uniform zigzag monopole antenna [20]. The pitch angle (α) which defines the angle between two zigzag segments, and the segment length (L), are the two essential parameters that fully characterize the structure as shown in Fig 6.1.

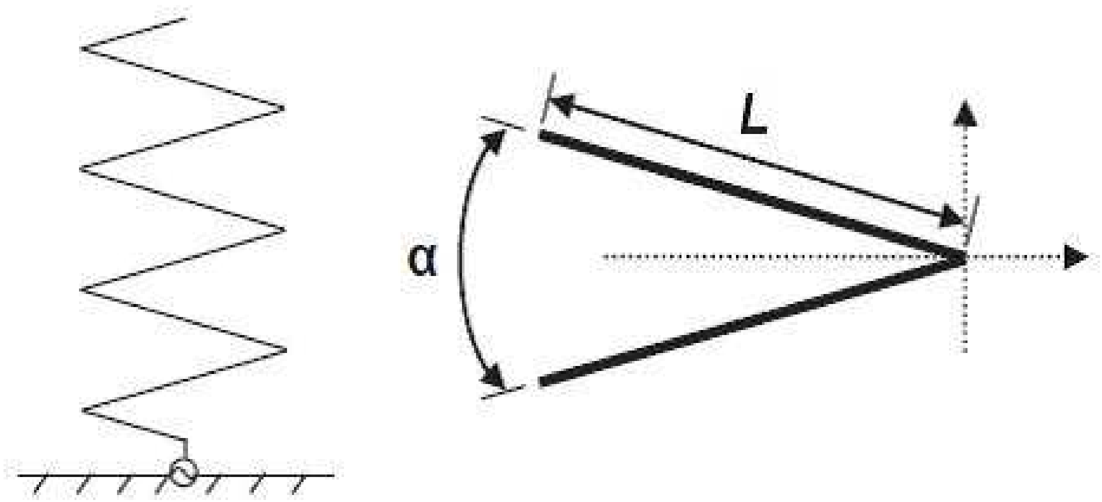


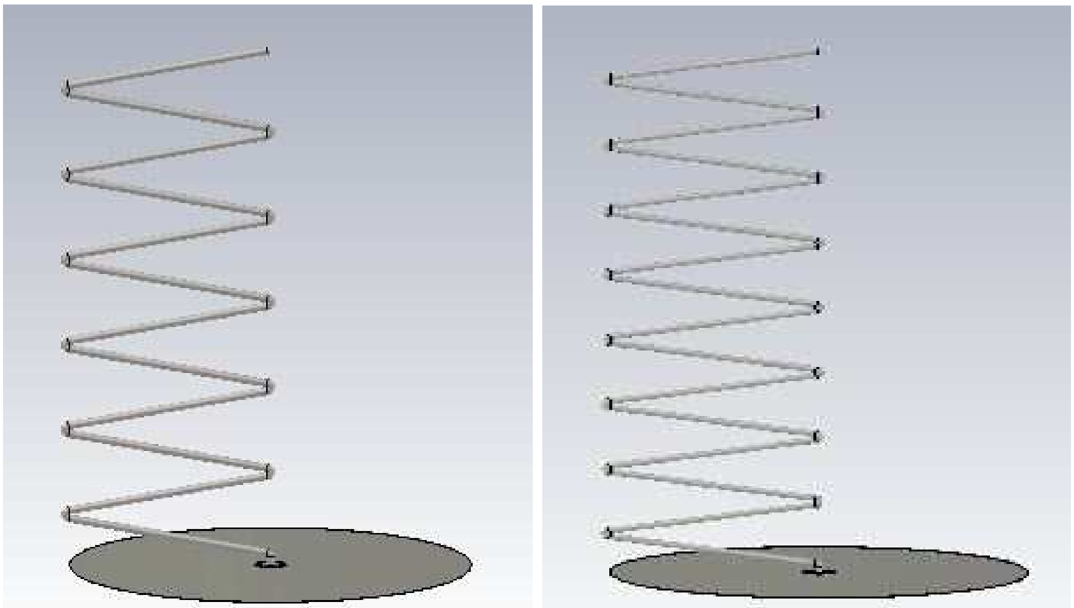
Figure 6.1: zigzag geometry

The single zigzag is shown diagrammatically in Fig 6.1. The coordinate system is chosen in such a way that the antenna lies entirely in the Y-Z plane, the axis of the antenna being along the Z-axis. The antenna is fed by a coaxial line whose inner conductor is connected to the antenna and the outer conductor is directly connected to the ground plane. Although the ground plane effects the performance of the antenna to some extent, especially regarding the back radiation, its main function is to offer a proper ground for the feed and the size of the ground plane is not critical for the required performance of the antenna.

Physically we can think of the antenna as a number of $V's$ connected in series. The length of each arm of the V and its angle should be chosen such that the radiation from all the $V's$ add in phase along $\theta = 0^0$ direction. The relation to be satisfied by the arm length L and the pitch angle (α) .In order to have maximum direction along $\theta = 0^0$ direction, the following equation must be satisfied

$$L(1 - sin(\frac{\alpha}{2})) = \frac{\lambda}{4}$$

This is the fundamental relation of designing a zigzag antenna[9].
For the 20^0 zigzag, the length of each arm (L) is chosen to be equal to 50.4mm so that above equation is satisfied at 3600MHz. For the other zigzags the arm length L is taken to be equal to the Proper value required by the corresponding angle. The ground plane in each case is of the dimension of the arm length at the frequency 3600MHz. a number of $6v's$ and $8vs$ of similar type of single v antenna are added in series and simulated the zigzag structures using a high frequency EM Simulator, CST MICROWAVE STUDIO 2015 a specialized tool for the fast and accurate 3D EM simulation of high frequency problems. CST designs of the proposed zigzag structures were shown in Fig 6.2.



(a) 6v's zigzag structure (b) 8v's zigzag structure

Figure 6.2: CST Design models of Zigzag antenna

It is found experimentally that the length of the feed has some noticeable effect on the pattern if it is greater than $\frac{\lambda}{4}$. With the increase of the feed length beyond $\frac{\lambda}{4}$ the direction of maximum shifts away from $\theta = 0^0$ direction towards the feed side. This is due to the fact that when feed length is large, it starts to radiate appreciably thereby effecting the end fire property of the antenna. The effect of feed length when it is less than $\frac{\lambda}{4}$ is not observable experimentally.

6.2 Simulation and Results

From Fig 6.4. it is found that considering the electrical length of the antenna (1.35λ) it has a very good directivity. It is clearly shown in polar plot that in both E-plane and H-plane gives endfire array radiation pattern. From this it appears that the antenna may be used very advantageously for directional purposes; it seems to be better than the commonly used antennas for this purpose at the VHF and UHF ranges. The return loss plot of the both structures is shown in fig 6.3. The measured half-power beam widths of the patterns and the corresponding side lobe ratios for designed $6v's$ and $8v's$

zigzag antenna structures at 3600MHz are shown in Table 6.1.

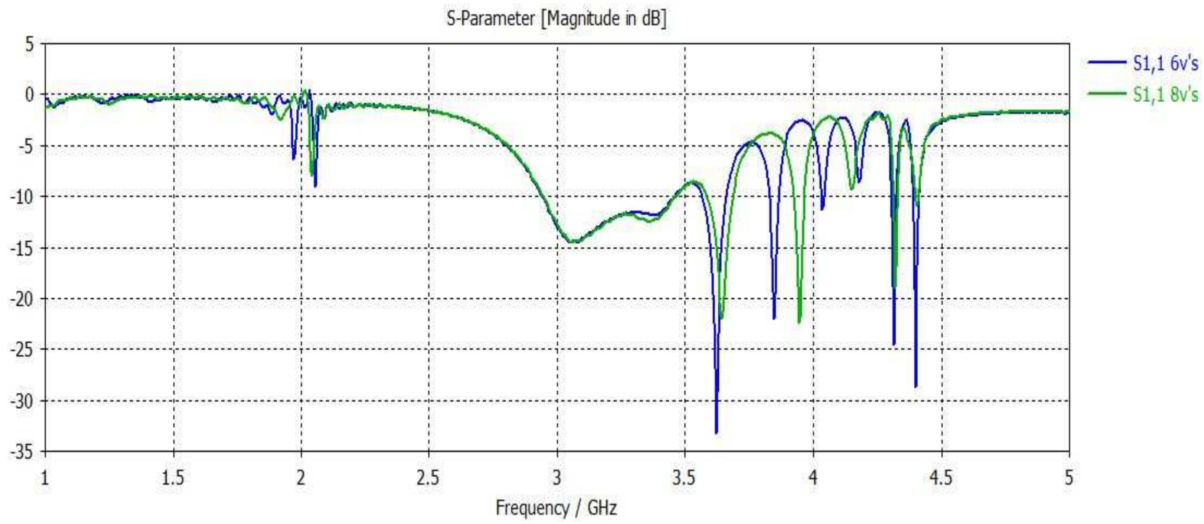
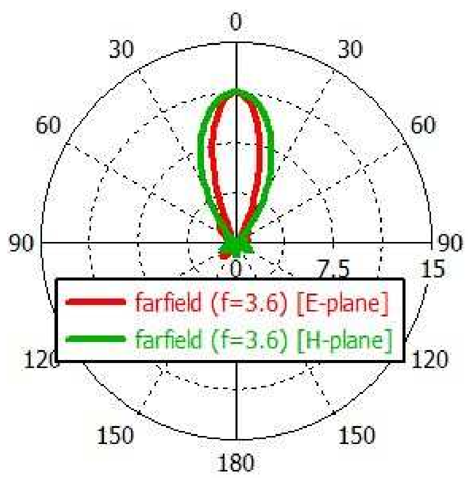


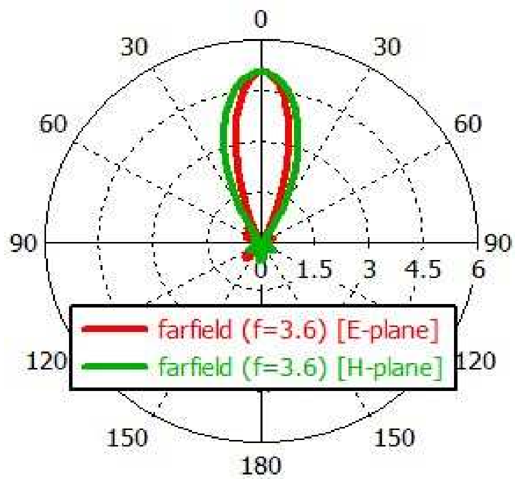
Figure 6.3: Return loss plot of both zigzag structures

Number of v's	Directivity(in dBi)	HPBW(degree)		SLL(dB)	
		E-plane	H-plane	E-plane	H-plane
6	10.50	35.6	54.1	-8.1	-9.6
8	11.83	31.9	44.4	-8.8	-9.5

Table 6.1: Directivity, HPBW, SLL for zigzag structures



(a) 6V's structure



(b) 8V's structure

Figure 6.4: Radiation pattern of Zigzag structures

Chapter 7

Conclusion and Future Scope

7.1 Conclusions

- Spherical microstrip antenna arrays are very useful to get obituary radiation patterns and to get multi beam radiation patterns. Though the directivity of the array is not high, radiation patterns comes satisfactory.

- Due to the planar nature and stripline mode of the Wilkinson power divider, it is very easy to design and fabricate. Wilkinson power divider is a loss less power divider when its all ports are matched. Equal and unequal arbitrary power divisions is possible with Wilkinson theory. Isolation between the output ports is achieved by introducing resistor in between the output ports. 3dB Insertion loss and return loss below 20dB achieved at the operating frequency.

- The frequency range of UWB as given by FCC in 2002 is 3.1GHz to 10.6GHz. A defective ground structure microstrip antenna is showing return loss below -10dB in the range 2.6GHz to 10.3GHz. The gain is varying from 1.913dB to 4.248dB and attain maximum at 10.3GHz. The radiation pattern gives Broad side radiation pattern in the E-plane and

Omni directional pattern in the H-plane.

- High directivity antennas are very useful in VHF and UHF range. Zigzag antenna is such type of antenna giving high directivity in a single direction. By increasing the number of Vs the directivity also increases. 8Vs structure is giving more directivity than 6Vs structure and both structures shows end-fire array radiation patterns in E-plane and H-plane.

7.2 Future work

- Interfacing designed spherical microstrip antenna array with designed power dividers and applying optimization algorithms to single element to get arbitrary radiation patterns.

- The operating frequency range of deigned UWB antenna is 2.6GHz to 10.6GHz is satisfactory in UWB range. But we need to improve the gain and radiation efficiency. By introducing rectangular slots on the patch we can do so.

- Designing of a Non uniform zigzag structure to get better efficiency and bandwidth. Study the radiation characteristic of zigzag antenna for different pitch angles.

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